Statement of Work

Aerodynamic Data Reduction and Dynamic Stability Analysis of the Crew Exploration Vehicle

1/02/08

Introduction:

This statement of work outlines the services requested for the analysis and synthesis of recent ballistic range and free/forced oscillation data for the improved understanding the parameters influencing dynamic stability test results. This analysis is to be conducted and concluded by January 1, 2009.

Overview of test:

The CEV project has conducted several ballistic range tests and free/forced oscillation wind tunnel tests on the CEV command module (CM) to obtain dynamic stability aerodynamic coefficients from supersonic to low subsonic speeds across a wide range of angle-of-attack. This effort will attempt to look at all available data (drawing on test data from other blunt capsule tests where appropriate) to compare the relative merits and hinderences of each test technique, quantify the differences in the data extracted from each test (identifying sources of disagreement where possible), and providing recommendations where each facility is best applied in obtaining data for the CEV database.

The following lists the tests performed to date that are candidates for this analysis:

Eglin Ballistic Range

1) TDASA-Apollo supersonic/transonic, BR test
2) CEV CM supersonic, transonic, subsonic BR test
3) MSL and MER ballistic range tests (different configuration)

Ames Ballistic Range:

1) HFFAF Lifting/Nonlifting CM ballistic range test
2) Other ?

NASA LaRC Spin Tunnel:

1) CEV CM spin tunnel testing (lifting/nonlifting)

NASA LaRC TDT:

1) Small amplitude, forced oscillation test
2) Large amplitude, forced oscillation test

Aberdeen Proving Grounds Free-Flight Ballistic Range

1) CEV CM (lifting/nonlifting) telemetered BR test

These sets of data can be compared to assess the limitations of each test technique and to see if direct measurements test data (wind tunnels) can be used to anchor the more open-ended curve-fitting analysis used in ballistic range data reduction.

The primary objective of this analysis is the comparison of each set of test data where overlaps in Mach number and Angle-of-Attack exist, quantifying observed differences and identifying sources of error. This type of comparison can be more difficult than the comparison of static force/moment data as two sets of pitch damping data with very different variations with Mach and angle-of-attack can produce very similar behavior when used in a simulation of an oscillating, decelerating blunt body. Therefore the available data shall be used in the simulation of available ballistic range data (here used as validation, scaled, flight data) to demonstrate the integrated effect of the dynamic stability data across Mach number and angle-of-attack.

Data to be supplied to the contractor:

The customer will provide the contractor all aerodynamic coefficient data in electronic/tabular form from each test that is to be analyzed under this task, with the exception of the Eglin and NASA Ames ballistic range data. The contractor was responsible for the data reduction of those tests and therefore already has this data and the accompanying simulations that were fit through the raw ballistic range data to extract dynamic stability coefficients. The customer will also provide trajectory data (orientation, location and velocity data) from the Aberdeen instrumented ballistic range test and motion histories from the NASA LaRC spin tunnel tests in addition to the dynamic aerodynamic coefficients. Details are noted in the tasks below.

Tasks to be completed by the contractor:

Task 1: Dataset matrix

The contractor shall generate a matrix of all provided data, highlighting overlaps in common variables and areas where test parameters (OML, Reynolds number, radial cg offset, etc.) differed. From this matrix, the contractor shall identify the data sets that will be compared in the following tasks.

Contractor and NASA will coordinate meeting with representatives from various facilities, where relevant information will be provided to contractor.

Task 2: Ballistic Range/Forced-Oscillation Wind Tunnel Data Comparison

The contractor shall compare and quantify the differences in dynamic stability as measured in dynamic wind tunnel tests and in ballistic range testing. Functional forms shall be fit through each set of wind tunnel test data for which there is comparable ballistic range data. Simulations using the best fit through wind tunnel dynamic stability data will be run to assess how well wind tunnel data replicates observed free flight data. The coefficients of the functional form shall also be relaxed to identify a best-fit using traditional ballistic range data reduction methods. A comparison of these analyses shall be performed identifying possible sources of discrepancy and an overall comparison of the data.

From this analysis, a final, best aerodynamic model shall be delivered for the range of Mach number and Angle-of-attack appropriate to the available data.

Task 3: Free-to-oscillate/Ballistic Range/Spin Tunnel data reduction comparison.

The contractor shall attempt to identify differences in the measured dynamic stability characteristics due to test setup and data reduction techniques between wind tunnel free-to-oscillate testing and ballistic range results and observed spin-tunnel flight dynamics. The data reduction techniques (including fits through ballistic range data) developed by the contractor for ballistic range testing shall be applied to free-to-oscillate test data. This objective of this task is to isolate the differences caused by sting interference, bearing friction, and other wind tunnel related effects from data reduction techniques and draw conclusions on the relative merit of each test technique. The contractor will document additional data required for a full analysis if needed (e.g. bearing friction measurements).

Qualitative and/or quantitative comparisons between free-to-oscillate and spin tunnel tests data will be conducted if sufficient data exists. NASA LaRC will supply available spin tunnel data to assess the feasibility of these comparisons.

Task 4: Investigation of Alternate Sources of Apparent Damping

The contractor shall investigate any history effects (hysteresis of the nominal pitching moment curve, or frequency/amplitude effects) and how such effects may distort or alter the identification of pitch/yaw damping coefficients in ballistic range as well as forced oscillation and free-to-oscillate wind tunnel tests. This analysis should compare current dynamic stability test techniques and their relative abilities in separating true dynamic stability from these other effects that alter oscillation amplitude growth (or measured damping forces) during testing.

The contractor will suggest any additional testing or improvements to test technique (control of oscillation frequency, amplitude, cg, freestream conditions etc.) that can help identify hysteresis effects.
NASA LaRC shall provide all available static aerodynamic data (wind tunnel and computational) to the contractor. This contractor will attempt to correlate any possible hysteresis effects identified in this analysis with existing static data.

Task 5: Uncertainty Analysis and Applicability Assessment for Alternate Cg Locations

The contractor shall assess the available data sets and document the uncertainties on aerodynamic coefficients identified by forced oscillation and ballistic range techniques (the two test techniques for which there is the most data). This uncertainty analysis should be done for a large sample of data for both techniques. The assessment should identify the significant sources of error associated with the test techniques as well as the amount of data. Particular attention shall be paid to modeling uncertainties such that dynamic stability curves with dramatically different functional forms (but similar integrated impact on trajectories) are reconciled and not over-conservatively bounded. Strengths and weaknesses of other techniques (e.g. free-to-oscillate and spin tunnel testing) should be addressed as well.

The contractor shall use available data to assess the sensitivity of dynamic stability coefficients to the location of the center-of-gravity. The dynamic forces and moments measured in TDT forced oscillation testing and their derivatives wrt rates shall be used to determine how effectively pitch/yaw damping coefficients may be transferred from on oscillation center to another using the dynamic moment transfer equations. The contractor shall document the moment transfer equations and a process for accounting for added uncertainties due to shifting the MRP, consistent with existing data. If the data does not permit transfer to another rotation center by any meaningful distance, this finding with supporting evidence shall be documented instead.

Task 6: Telemetetry Data Evalutation

The contractor shall assess the available Aberdeen Proving Grounds telemetered ballistic range data collected for CEV. Data will be collected in the first half of calendar year 2008 for this analysis. The data will include magnetometer, rotational rate, accelerometer, and potentially forebody pressure data, all anchored by radar tracking (position and velocity) data. The objective of this task is to assess the data quality and make recommendations regarding how best to use this data. The contractor shall provide analysis showing whether the data can be used to directly solve for dynamic stability coefficients as a function of angle-of-attack and Mach number, or if multiple shots are required just as is done with testing in Eglin AFB and NASA Ames ballistic ranges. NASA LaRC will supply all raw data to the contractor and be responsible for converting forebody pressure data into instantaneous angle-of-attack and sideslip for correlation other rate/accelerometer measurements. The contractor will also assess the suitability of these particular data sets and this type of data in general as validation cases to evaluate aerodynamic databases for use in 6-DoF trajectory simulations.

Task 7: Reporting:

The contractor will supply a preliminary written report 4 months after the start of these tasks. A final written report shall be supplied within 7 months of the start these tasks. Periodic updates of significant and/or unanticipated results, determined prior to these dates, will be communicated to the customer informally by telephone, e-mail etc. Upon completion of the preliminary report, the contractor will then participate in a teleconference with the customer to address and concerns. Three months after this teleconference, the contractor will supply a final report. This report is to include data produced in the completion of Tasks 1-5.

Deliverables

1.	Dataset matrix of all data to be evaluated, noting overlaps from data set to data set. (Task 1)	**April 1, 2008**	**Format: informal report, documenting results.**
2.	Comparison report of forced oscillation results with ballistic range trajectory data. (Task 2)	**June 1, 2008**	**Format: informal report, documenting assumptions, models, and results**
3.	Free-to-Oscillate, Spin Tunnel, Ballistic Range test technique comparison report. (Task 3)	**August 1, 2008**	**Format: informal report, documenting assumptions, models, and results**
4.	Hysteresis evaluation report. (Task 4)	**Sept. 30, 2008**	**Format: informal report, documenting assumptions, models, and results**
5.	Uncertainty analysis report (Task 5).	**Dec. 31, 2008**	**Format: informal report, documenting assumptions, models, and results**
6.	Assessment of APG telemetry data for use in dynamic coefficient identification and as validation data set.	**Dec. 31, 2008**	**Format: informal report, documenting assumptions, models, and results**

Sole Source Justification

Aerospace Computing, Inc., possesses world-class expertise in the field of blunt vehicle aerodynamics. They have successfully provided ballistic range data reduction analysis to NASA Langley during FY2000, FY2001, FY2002, FY2005 and FY2006. As part of this previous support, software tools were developed for the reduction of free flight attitude information into aerodynamic coefficients of blunt entry vehicles. These modified tools are not available from other vendors. It is to the advantage of the Government, to leverage the previous investment to obtain the requested work in the most cost-effective and timely manner.